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Beidou Time Synchronization Receiver for Smart Grid

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Abstract

A time synchronization system based on the Chinese GPS system i.e. Beidou or Compass for smart grid applications is illustrated. A time synchroni-zation Beidou receiver with self-designed radio frequency IC (RFIC) is presented. The receiver provides precise one pulse per second (1PPS) timing service for the smart grid.

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Keywords: Beidou receiver, timing synchronization, smart grid

1. Introduction

Power grid is showing increased dependence on the high precise timing. From the perspective of building a robust national wide system, satellite timing synchronization is the foundation. It supports the society from all angles and thus becomes the certain trend in the future. The voltage, current, phase angle, and power angle of a power system are all a function of time. Power grid cannot run stably and safely without automatic detection, monitoring and control. High precise synchronized timing of the power grid is in urgent demand for relay protection, event remote terminal units (RTU), energy management system (EMS), digital power technique on-line precision system (OPS) and wide area measurement system (WAMS). Current available satellite timing synchronization systems are U.S. GPS, Russia GLONASS, Europe Galileo and Beidou (so called Chinese GPS or CMOPASS).

GPS timing synchronization has already been used in many areas. GPS receivers measure the time difference between 1 pps output of a local clock and GPS time using the standard common method [1], [2]. These tracking schedules are published periodically by BIPM [3]. GPS timing synchronism typically uses satellites to deliver precise time signal which coverage all of the earth while having high precise time error about 10~20ns [4]. Due to the security concern about self-owned property rights [5], Chinese state grid decides to use Beidou for timing synchronization instead of GPS.

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To satisfy the need on timing synchronization of the power grid business, analyzing and realizing synchronization technology with Beidou navigation system in power grid are necessary. The purpose of this paper is to illustrate the challenging of the Beidou timing synchronism system and simply evaluate the architecture of the Beidou timing system. This paper also presents a Beidou synchronization receiver for Chinese smart grid. The receiver consists of a compact antenna, a highly integrated RFIC and baseband circuitry. The synchronization referred in this paper means clock at each node in a power grid are synchronized to the Universal Time Coordinated (UTC).

2. Using Beidou in Smart Grid

Beidou satellites navigation system is a position system developed by China and its first generation BD-1 was completed in 2003. BD-1 system is composed of two synchronous satellites, an earth center and user terminals. It is a two way system and its uplink and downlink frequency bands are 1610~1626.5MHz (L-Band) and 2483.5~2500 MHz (S-Band) respectively [7].

2.1. Beidou Timing Service

Beidou can provide timing service in two modes: one-way timing and two-way timing as illustrated in Fig. 1.

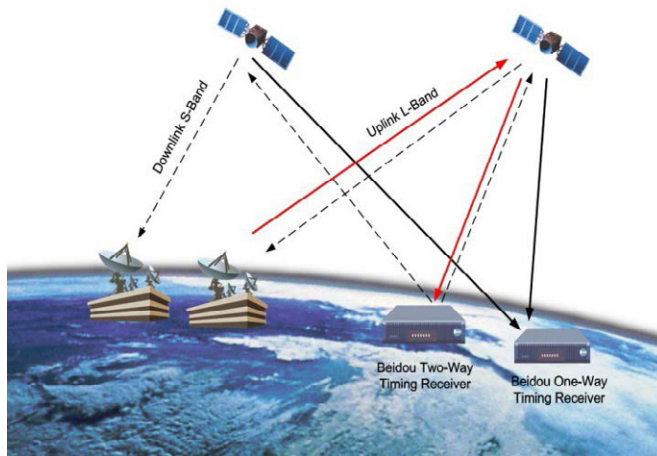


Fig. 1. Beidou timing synchronization system

In one-way timing mode, a ground receiver receives the clock signal from Beidou satellites directly without the earth center's interaction. Then receivers measure the time difference between the 1 pps output of a local clock and Beidou time, and output a synchronized accurate timing signal. In two-way timing mode, the satellite interacts with the ground center at where the time difference is calculated. Then the difference is transmitted to the ground receiver via Beidou satellites. The accuracy of one-way mode is 100ns while two-way mode is 20ns. However the system resource occupied in interacting with the ground station in the two-way timing mode limits the system capacity, whereas one-way timing is a passive mode and needs no system capacity. The only drawback of a one-way timing is that the coordinator of position of the user terminal needs to be known beforehand.

2.2. What time precision the smart grid needs

Different part of the smart grid needs different precision degree of timing. Table 1 lists vary of requirement needed by each part.

The table shows that the most accurate timing requirement is 1us. Therefore, Beidou one-way timing service with 100ns time precision can fully satisfy the requirement.

Table 1. Timing accuracy the smart grid required

Service System	Signal Type	Signal accuracy	Signal Interface
Traveling Wave Fault Location	Second Pulse and Time Message	1us	Static null contacts
Lightning Location System	Second Pulse and Time Message	1us	RS-232
Power Angle Measurement System	Second Pulse and Time Message	40us	RS-232
Fault Recorder	IRIG-B or Sub-Pulse Time Message	1ms	RS-422
Sequence of Events Recorder	IRIG-B or Sub-Pulse Time Message	1ms	RS-422
PC Protective Devices	IRIG-B or Sub-Pulse Time Message	1ms	RS-422
Level Automatic Dispatching System	IRIG-B or Sub-Pulse Time Message	1ms	RS-232
Substation Monitoring	IRIG-B or Sub-Pulse Time Message	1ms	RS-422
Load Monitoring System	Time Message	≤0.5s	RS-422

2.3. Beidou synchronization principles in smart grid

As illustrated in Fig. 2, each level of the smart grid receives the timing signal from Beidou satellites independently from state grid to city grid. Rubidium clocks are used as local timing. Beidou satellite timing system with high precise time reference adjusts and synchronizes the local rubidium clock to reduce the time error at all levels.

Timing receiver calibrates the clock by receiving Beidou broadcast information. The first sequence in one period sent out by the ground control center includes standard Beidou time information (day, hour, minute and time calibration data), satellite location information, and time reference which is delayed by varies ways including transmission delay induced by ground center to satellite, satellite to receivers and other ways including troposphere, ionosphere and Sagnac effect. Taking the delay, the satellite location and receiver location into account, the receiver outputs the timing signal after the calculation.

Generally, it is good enough to get precise time information by observing one satellite. However, receiving signals from two or more satellites simultaneously will improve the accuracy and the reliability. Additionally, In order to get the highly precise measurement, the calibrating from different satellites is carried on the observation data to eliminate the error item, such as satellite orbit errors and ionosphere delay errors.

2.4. Challenging of Beidou in Precise Timing

The downlink frequency band of Beidou satellites is 2483.5~2500MHz. The spread spectrum signals transmitted by the satellite are very low power at the Earth's surface even below the noise floor. Therefore the antenna cabling must be designed to provide sufficient signal to the receiver. Meanwhile the receiver must have a good sensitivity of better than -128dBm, low noise figure and large dynamic range.

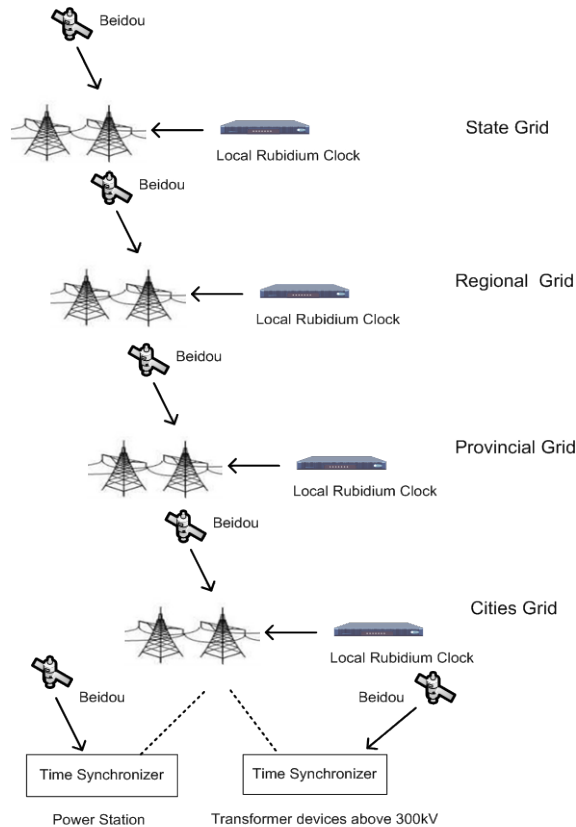


Fig. 2. Illustration of Beidou timing synchronization for smart grid application

Beidou signals are susceptible to interference from external sources. Most timing applications of Beidou are at wireless infrastructure locations where there are high power RF transmitters. RF interference can cause the Beidou signals to be jammed, which will cause the receiver equipment to lose lock on the Beidou signals. So the Beidou receiver must have excellent filtering performance which is the key to get the precise time signal in the synchronization system.

Baseband demodulator must be taken into the Beidou timing system design. The algorithm must be designed for high precise timing to be demodulated reliably under low input power.

3. Beidou Timing Receiver

The receiver is mainly made up of antenna, RF front end, AD converter and baseband processing as

illustrated in Fig. 3. For timing synchronization receiver must be able to catch the satellite signal and demodulate the clock signal. The weak signal of satellites is first received and amplified by active antenna module, then transformed to RF receiver module through a cable. The receiver amplifies and converts RF signal to an IF signal. The IF signal is then sent to baseband module for demodulation and decoding processing. The timing signal is then extracted.

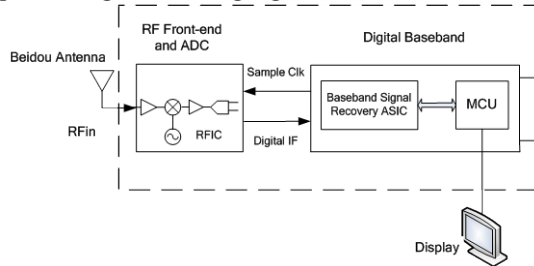


Fig. 3. BD-1 one-way timing receiver architecture

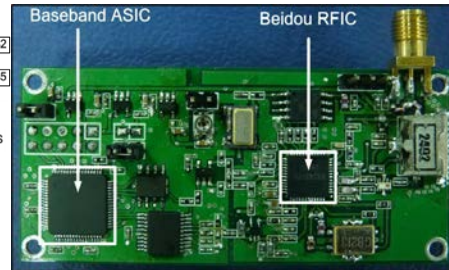


Fig. 4. The PCB of the Beidou receiver for timing system

3.1. Design of RF Module

The core of the RF module is the RFIC that designed on our own. It adopts the super-heterodyne conversion scheme for the advantage of low-cost and high-integration. LNA, Mixer, BPF, VGA, PLL and A/D are all integrated in this chip. With temperature compensation techniques, the chip can work stably in the temperature range of -40°C to $+125^{\circ}\text{C}$ as shown in Fig. 4.

The received satellite signal from antenna is sent to the low noise amplifier (LNA) firstly, and after filtering (BPF) the RF signal is amplified by IF LNA.

To reduce the effects of the high power out-band signals, good rejection performance of filter is needed, especially in timing applications. The fourth order Chebychev LPF with an on-chip RC tuning circuit is designed by using active RC filter structure. The bandwidth of the input filter is comparatively wide and the side roll off is sharp, and the pass band ripple is below 1dB, the outside side has a large rejection of 40dB. The super-heterodyne architecture greatly improves selectivity and immunity to jamming signals of the receiver.

With automatic gain control and temperature compensation techniques, a stable VGA with a large gain range is realized.

3.2. Design of Baseband Module

The baseband of this system uses an ASIC to process the digital demodulation, realize one-way synchronization, and deal with communication protocols providing output 1pps timing signal. Applying the ASIC chip can improve the reliability, reduce the cost, scale down the receiver, reduce the data bit error ratio, and increase the timing precision. The photo of the receiver is shown in Fig. 4.

4. The Result

The major performances are tabulated in Table 2. The high-low temperature tests are carried out on the timing service block including receiver and baseband parts. The synchronization accuracy of the system satisfies the technical requirements for the smart grid. The Beidou timing service block with UTC time output signal has three parallel channels and tracking ability of three satellites, supports RTC function. Receiver can set clock and date when no satellite signal available.

Table 2. Major performance of the receiver

Parameter	Description
Receiving signal selectivity	-127.8dBm
Second pulse (1pps)	Error time 92ns (position initial); Duty-cycle: 50%
Locking time	Clock locking time less than 3 minutes (1pps)
Voltage supply	5V
1PPS signal voltage	3.3V LVCMOS
Power consumption	<3W

5. Conclusion

Using Beidou is a cost effective approach for precise timing applications. With developments of the synchronization technology in a power system, most transformer stations adopt the integrated automation, remote centralized control and operation. This enhances the production efficiency and reduces the error operation. So an automatic timing synchronization system is the base of a power system.

A Beidou timing synchronization receiver is reported. It features low power, high reliability, less external parts and low cost which can realize the precise timing synchronization for the smart grid. The device has practical application value. The receiver presented in this paper offers frequency signal including the standard frequency signal of the output 1pps and serial code data. The timing system can also be used for radar tracking, communication synchronization and intelligent transportation timing.

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